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The study of electric discharge initiated pulsed COIL with volume generation of atomic iodine

(From 1 August 2000 to 30 April 2001 for 9 months)

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14. ABSTRACT
This report results from a contract tasking P.N.Lebedev Physical Institute, with results as follows:

The experiments with pulsed COIL initiated with a longitudinal electric discharge showed the initiation length up to 60 cm is available in the active medium conditions close to that of cw laser.

It is shown the active medium temperature growth after discharge can be responsible for the specific output energy drop as compared to photolytic initiation.

The laser effect is obtained with the pulsed COIL based on the jet singlet oxygen generator. The operation pressure is obtained under the total pressure of 17 Torr and oxygen partial pressure of 7 Torr. The laser operation under the high pressure makes it possible to reduce the pump rate and, thus, to minimize the weight and size of the laser.

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The objective of this project is to study the features of operation of electric discharge initiated pulsed COIL with volume generation of atomic iodine. The work included an investigation of influence of the length of discharge gap on performance of pulsed COIL initiated with longitudinal discharge and an investigation of transverse discharge initiated pulsed COIL based on the Jet Singlet Oxygen Generator. The region of 10 to 60 cm of discharge gap length has been investigated. The lasing of Jet SOG pulsed COIL has been obtained for the first time. The operation pressure of 17 Torr has been obtained.

Keywords : Gas Laser, Chemical Oxygen- Iodine Laser, Pulse mode, Experiment, Performance, Singlet oxygen generator, Iodide

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Contents

1. Introduction

The object of the project is to study the features of the operation of the pulsed COIL with volume generation of iodine atoms in a glow discharge. It includes three independent works:

- optimization of the operation parameters of a jet singlet oxygen generator (JSOG) to minimize the content of the residual chlorine and eliminate the energy losses at stage of the forming the active medium,
- investigation of the influence of the discharge length on the parameters of the pulsed COIL initiated with the longitudinal electrical discharge,
- investigation of the pulsed COIL based on the jet singlet oxygen generator.

To solve the first problem the operation parameters – chlorine flowrate, jet velocity, working solution composition were varied under the monitoring the chlorine content by the absorption spectroscopy. Thus, the operation mode with minimal chlorine content were found.

The laser output parameters – output energy, pulse duration delay time – were measured for dischage gap length of 10, 20, 30 ,40,and 60 cm in experiments with a pulsed COIL initiated with longitudinal electric discharge. Oxygen pressure, sort and partial pressure of a buffer gas, voltage and capacitance were variable parameters.

The transverse resisitively stabilized discharge was used to initiate the 5 cm gain length pulsed COIL with jet singlet oxygen generator. The influence of operation conditions – oxygen pressure, discharge energy, sort and partial pressure of buffer gas – were under investigation.

2. Optimization of the Jet SOG operation to minimize the residual chlorine content.

Application of a method of instantaneous volume ge neration of iodine atoms to produce pulse operation of chemical oxygen iodine laser (COIL) was successfully demonstrated when sparger singlet oxygen generator (SOG) was used as a source of singlet oxygen [1]. The essence of the method is preliminary mixing of singlet oxygen with iodide not reacting with it and then instantaneous forced decomposition of iodide releasing free iodine atoms. So far photolysis and electric discharge were used to decompose iodide [2,3]. Unlike pholytically pumped iodine laser (PIL) pulsed COIL with volume generation of iodine atoms does not require to use only iodides forming excited atoms under decomposition. Due to this fact the number of iodides which can be used as iodine atoms donor is very wide. So far the alkiliodides $C_nH_{2n+1}I$ and perfluoroalkiliodides $C_nF_{2n+1}I$ were investigated. $C_nH_{2n+1}I$ was shown to produce higher output energy but only when chlorine concentration in the SOG effluent is very low. Such a behavior is a result of chemical dissociation of iodide in the mixture of $C_nH_{2n+1}I$, singlet oxygen and molecular chlorine [4]. So far the exact mechanism of generation of iodine atoms is unknown but is was shown the rate of reaction is proportional to product of iodide concentration by that of singlet oxygen and chlorine. Thus the brutto-reaction can be written as follows:

$$C_nH_{2n+1}I + O_2\,(^1\Delta) + Cl_2 \rightarrow I + \text{products}$$

The rate constant of this reaction was been estimated as high as $4\cdot10^{-32}$ cm^6s^{-1} [4]. At the same time this process for $C_nF_{2n+1}I$ is too slow to be detected with apparatus available.

The release of the free iodine atoms results in relaxation of energy stored in active medium. It makes impossible to form the large dimension active medium.

The sparger SOG generates singlet oxygen with very high chlorine utilization but low operation pressure. Both the theory and experiment predict an increase of the output energy proportionally to the singlet oxygen pressure. Thus application of high pressure SOG promises significant increase of specific output energy of pulsed COIL with volume generation of iodine atoms.

Jet SOG (JSOG) makes it possible to generate singlet oxygen at rather high partial pressure. Unfortunately, the chlorine utilization is not too high. As soon as the mechanism of the reaction is not understood in detail one can not answer the question what is the acceptable level of chlorine

utilization. So the goal of the fist stage of investigation is a search for the JSOG operation mode providing as low chlorine concentration as possible.

2.1. Experimental

2.1.1. Jet singlet oxygen generator.

The traditional design counter flow jet singlet oxygen generator of 4 cm internal diameter was used. The jets were formed with an assembly of 120 tubes of 0.7 mm i.d. The length of jets or reaction zone (distance from jets injector edge to the point of chlorine injection) was as long as 14 cm. The calculated value of specific surface area for smooth jet was 2. cm^{-1}.

The working BHP solution was prepared in a separate vessel providing mixture cooling during the dilution process. Before utilization the working mixture was cooled down to -10^0 C. Medicine purity hydrogen peroxide of 38 % concentration and 12 N water solution of high purity KOH were used to prepare 4 l of working BHP. The jets were driven with atmospheric pressure. This volume was enough to provide the runtime of 17 s.

2.1.2. Measuring of the chlorine concentration.

The method of absorption spectroscopy was used to measure the residual chlorine concentration or chlorine utilization. The schematic diagram of experiment is shown in the Fig. 1. The home-made tunable repetitively pulsed Xe-laser was built as a source of λ = 365 μm radiation.

The measurements of chlorine concentration were carried out keeping in mind the future application of a discharge chamber in a laser experiments with gain length of 5 cm. This value was too small to provide a detectable level of absorption signal. To increase the absorption length the special "optical ears" were attached to the chamber and double pass configuration was used. Due to these measures the absorption length was increased up to 125 cm. Both "optical ear" were connected to pump system to provide slow flow of mixture investigated.

The beam from Xe-laser was splitted by beam splitter BS producing the reference signal (FD1) and input one (FD3). The FD2 detected the absorbed radiation. The differential amplifier extracted the difference signal of FD3 and FD2. The filter F served to balance the differential circuit. The difference signal and reference one were recorded with a dual-beam digital store oscilloscope DSO based on the personal computer. Thus one had necessary data to calculate the chlorine concentration. The sensitivity of method used made it possible to detect chlorine concentration down to 0.02 torr.

2.2. Experimental results

The level of chlorine utilization depends on partial chlorine pressure, velocity of both jets and gas, BHP composition, specific surface area. Under our experimental conditions only three parameters could be varied: chlorine pressure, gas velocity, base concentration. The variation of gas velocity was obtained due to injection of buffer gas N_2 downstream of the SOG. All experiments were made with a pump capacity determined by sonic orifice of 10 mm in diameter placed downstream of the discharge chamber.

The matrices of experimental results for two values of KOH concentration in BHP are presented in Table 1 and Table 2, where V_{liquid} is the jet velocity, M_{buffer} and M_{Cl2} is the flowrate of buffer gas and chlorine respectively, V_g is a gas velocity, P_{Cl2} is a residual chlorine pressure.

Table 1

[KOH] = 3.9 mol/l, V_{liquid} = 4.3 m/s , σ_{SOG} = 2.1 cm^{-1}

M_{Cl2} (Torr·l/s)	M_{buffer} (Torr·l/s)	P_{SOG} (Torr)	V_g (m/s)	P_{Cl2} (Torr)	η_{Cl2} (%)	T_{SOG} (°C)
152	250	34	3.5	0.7	5.5	-12
152	250	30	4.0	0.24	2.1	-10
207	250	38	4.3	2.5	14.5	-10
207	250	38	4.3	1.3	7.4	-10
271	250	42	5.1	2.2	10	-9.5

271	250	43	5.0	3.5	15.6	-10
152	400	40	3.0	0.3	2.7	-10.5
207	400	46	3.6	1.3	8.2	-11
271	400	52	4.1	2.0	9.5	-10
152	710	61	2.0	0.35	3.3	-10.5
207	710	70	2.3	2.1	13.3	-10.5
271	710	76	2.8	5.2	24.8	-11
271	710	76	2.8	6.0	28.7	-10.5

Table 2.

[KOH] = 5.9 mol/l , V_{liquid} = 4.3m/s , σ = 2.1cm^{-1}

M_{Cl2} (Torr·l/s)	M_{buff} (Torr·l/s)	P_{SOG} (Torr)	V_g (m/s)	P_{Cl2} (Torr)	η_{Cl2} (%)	T_{SOG} (°C)
152	250	24	5.0	0.05	0.55	-9
152	250	28	4.3	0.04	0.37	-8.2
207	250	37	4.4	0.2	1.2	-8
271	250	45	4.8	0.66	2.8	-7.5
207	106	26	6.2	0.07	0.4	-7
271	106	34	6.3	0.59	2.4	-7
271	106	36	6.0	0.75	2.9	-9
152	400	43	3.9	0.11	0.9	-6.5
207	400	49	3.3	0.12	0.7	-7
271	400	55	3.9	1.02	4.3	-7.5
271	400	59	3.6	0.75	3.6	-7

One can see the very low residual chlorine pressure can be obtained at increased base concentration at respectively high pressure. The pulsed laser operation pressure is planned to be about 10 Torr. It is obvious the chlorine utilization at this pressure should be higher.

The results obtained may seem not to be so interesting today when there is a lot of investigations on JSOG operation. But the work carried out confirms the apparatus works in a satisfactory agreement with theory predictions and can be used in laser experiments.

It should be noted as a negative factor the presence of BHP drops in a flow. These drops falls on the electrodes thus making problems with discharge forming.

3. Influence of discharge gap length on the performance of longitudinal discharge initiated pulsed COIL.

The goal of this work is investigation of the influence of the length of the longitudinal discharge gap on the pulsed COIL output parameters. Saying on longitudinal discharge we have in mind the discharge geometry where the distance between the electrodes significantly exceed the electrode size. So one can see that shortening the discharge gap results in discharge geometry more close to transverse one.

As it was shown in the works carried out in Lebedev Physics Institute the application of such a discharge to initiate the pulsed COIL with volume generation of iodine atoms makes it possible the laser to operate with a high electrical efficiency close to 100 % at specific output energy of 0.5 J / l per 1 Torr of O_2. The laser operation at a length of discharge gap of 60 cm was demonstrated. The application of a glow discharge to generate iodine atoms in the gas mixture containing the singlet oxygen to form COIL active medium is not trivial task. Indeed, the electrical discharge produces electrons, ions, and molecular fragments. The sort and concentration of these components, in general, depend on discharge parameters - mainly discharge energy and reduced

strength of electric field E/N. Besides, the length of the discharge gap determines the resistance of plasma channel and, hence, the energy deposition into the active medium.
Thus the optimization of discharge parameters to improve the energy parameters of the laser is a crucial task and variation of the length of the discharge gap allows one to vary latter parameter keeping the voltage constant.

3.1. Experimental

The schematic diagram of experiment is shown in a Fig.2. The discharge chamber is mounted in one of the shoulders of experimental facility used in investigations of a pulsed COIL initiated with a longitudinal discharge [3]

The discharge chamber, 39 mm i.d., is made of PMMA. The chamber has 5 electrode holes. The electrode section of typical flash lamp, 20 mm o.d., is chosen to work as a cathode. These sections are inserted into electrode holes and sealed. The annular electrode is a common anode. To eliminate the influence of near electrode regions the electrodes are carried out the laser cavity area. Thus, the discharge positive column processes only form the laser active medium.

The discharge chamber with a moving annular cathode was investigated too. But this design was abandon due to instability of results obtained.

The electrical discharge fed by a capacitor bank is triggered with a thyratron TGI-25/1000 operating at a voltage up to 25 kV. The capacitor bank is assembled of several disk ceramic capacitors. Variation of both the voltage and the number of capacitor makes it possible to change the discharge energy.

The singlet oxygen is produced in the sparger type SOG packed with Rushig rings to, firstly, intensify the mass-transfer and, secondly, to prevent ejection of BHP from SOG. The buffer gases (N_2, Ar, SF_6) is fed trough the SOG in a mixture with chlorine. The typical pump capacity in experiment is 80 l / s. The previously made measurements of the dependence of singlet oxygen yield on pump capacity allow us to evaluate the value of SO yield under different experiment conditions.

The laser operation at different length of the discharge gap is compared by output specific energy and efficiency, i.e. ratio of output specific energy to specific deposition energy. But output laser energy depends on the level of threshold exceeding, which, in its turn, depends on the gain length, i.e. length of the discharge gap. The 0.8 % transmission of the output spherical mirror of laser cavity is chosen to minimize this effect (the transmission of about 4 % is optimal for majority of experimental conditions). The 0.05 % transmission spherical mirror is chosen as a totally reflecting one. The laser output energy is limited with an external 30-mm diameter diaphragm installed 45 cm from output mirror.

The output laser energy emitted from aperture 30 mm is measured with IMO – 2N, the pulse shape is recorded with a store oscilloscope and then is recorded with a digital camera Kodak DC-240.

3.1. Results and discussion

All experiments are carried out with an operation mixture of 1 Torr O_2 and 0.5 Torr CF_3I. Helium, nitrogen and sulfur hexafluoride are used as buffer gases.

The results of experiments carried out for five values of discharge length are presented in Tables 3 – 7, where:

P_{buffer} – partial pressure of the buffer gas, Torr
U_{disch} – capacitor bank voltage, V
E_{reg} – measured output energy, mJ
E_{bank} spec – specific deposition energy (ratio of stored energy to discharge volume), J / l
E_{out} spec – specific output energy (ratio of output energy to the laser emitting volume), J / l
η_{electr} – electrical efficiency (E_{out} spec / E_{bank} spec), %
$T_{1/2}$ – pulse duration (FWHM)
? $_{pic}$ – picture number

E / N – reduced strength of electric field, Td
The hyphen in the cell of $T_{1/2}$ column means the picture is not made.

Table 3. Discharge length is10 cm, discharge volume is 120 cm^3, laser emitting volume is 72 cm^3.

Run ?	P_{buffer} Torr	U_{disch} V	E_{reg} mJ	E_{bank} specif J / l	E_{out} specif J / l	η_{electr} %	$T_{1/2}$ µs	? pic	E / N Td	Remarks
Buffer=He										
C=3.4 nF										
1.1	3	15	8	3.2	0.12		-	-	1042	
2.1		20	9	5.7	0.14		-	350	1389	
3.1		10	5	1.4	0.08		-		694	
4.1		15	10	3.2	0.15		-		1042	
5.1	5	20	10	5.7	0.15		-		962	
6.1		10	8	1.4	0.12	9%	27	351	481	
7.1		15	11	3.2	0.17		18		721	
8.1		20	13	5.7	0.20		18		962	
9.1	8	10	4	1.4	0.06		34	352	329	
10.1		15	12	3.2	0.19		17		493	
11.1		20	14	5.7	0.22		16		658	
12.1		20	13.5	5.7	0.21		-		658	
13.1		20	13	5.7	0.2		--		658	
C=10.2 nF										
38.1	3	15	1	9.5	0.02		-		1042	
39.1	5	15	5.8	9.5	0.09		-		721	
40.1	8	15	7.8	9.5	0.12		-		493	
41.1		20	7	17	0.11		9	358	658	
42.1		15	6	9.5	0.09		12		493	
43.1		10	7	4.3	0.11		14		329	
C=3.4 nF										
44.1	8	20	13	5.7	0.2		14	359	658	
C=6.8 nF										
45.1		20	11.5	11.4	0.18		10	359	658	
46.1		15	9	6.4	0.14		-		493	
C=10.2 nF										
47.1		20	4.5	17	0.07		10	360	658	
48.1		15	6	9.5	0.09		12		493	
Buffer=N_2										
C=3.4 nF										
14.1	3	10	3	1.4	0.05		35	353	694	
15.1		15	9.5	3.2	0.15		17		1042	
16.1		20	10	5.7	0.15		16		1389	
17.1		20	10	5.7	0.15		-		1389	
18.1	5	20	10	5.7	0.15		14	354	962	
19.1		15	8	3.2	0.12		21		721	
20.1		10	1	1.4	0.02		-		481	
21.1	8	10	0	1.4	0		-	355	329	
22.1		15	7	3.2	0.11		19		493	
23.1		20	9	5.7	0.14		17		658	
C=10.2 nF										
35.1	3	10	0	4.3	0		-		694	
36.1		15	0	9.5	0		-		1042	
37.1		20	0	17	0		-		1389	
Buffer=SF_6										
C=3.4 nF										
24.1	3	20	6.5	5.7	0.1		17		1389	
25.1		10	0	1.4	0		-	356	694	

26.1		15	5.5	3.2	0.09		19		1042	
27.1		20	7	5.7	0.11		-		1389	
28.1	5	20	4.5	5.7	0.07		-		962	
29.1		15	0	3.2	0		-		721	
30.1		20	5	5.7	0.08		14	357	962	
31.1	8	20	0	5.7	0		-		658	
C=10.2 nF										
32.1	3	20	0	17	0		-		1389	
33.1		20	0	17	0		-		1389	
34.1		15	0	9.5	0		-		1042	

.

Table 4. Discharge length is 20 cm, discharge volume is 240 cm^3, laser emitting volume is 144 cm^3

Run ?	P_{buffer} Torr	U_{disch} V	E_{reg} mJ	E_{bank} specif J / l	E_{out} specif J / l	η_{electr} %	$T_{1/2}$ μs	? pic	**E / N Td**	**Remarks**
Buffer=He										
C=3.4 nF										
1.2	3	15	33	1.6	0.25		-		521	
2.2		15	31	1.6	0.24		-		521	
3.2		15	32	1.6	0.24		-		521	
4.2		10	-	0.71	-		-		347	No disch
5.2		15	31	1.6	0.24		38	401	521	
6.2		20	31	2.8	0.24		28		694	
7.2	5	20	34	2.8	0.26		26	402	481	
8.2		15	31	1.6	0.24		37		361	
9.2		10	14	0.71	0.11		>70		240	
10.2	3	10	21	0.71	0.16	23%	>70	403	347	
11.2		15	29	1.6	0.22		35		521	
12.2		20	31	2.8	0.24		30		694	
13.2	8	20	34	2.8	0.26		26	404	329	
14.2		15	30	1.6	0.23		37		247	
15.2		10	17	0.71	0.13		58		164	
C=10.2 nF										
50.2	3	10	15	2.1	0.11		22	415	347	
51.2		15	13	4.8	0.1		17		521	
52.2		20	7	8.5	0.05		12		694	
53.2	5	20	20	8.5	0.15		12	416	481	
54.2		15	18	4.8	0.14		16		361	
55.2		10	13	2.1	0.1		28		240	
56.2	8	10	20	2.1	0.15		38	417	164	
57.2		15	21	4.8	0.16		18		247	
58.2		20	14	8.5	0.11		12		329	
C=20.4 nF										
59.2	3	10	7	4.2	0.05		14	418	347	
60.2		15	2	9.6	0.02		9		521	
61.2		20	0	17	0		-		694	
62.2	5	10	9	4.2	0.07		15	419	240	
63.2		15	2	9.6	0.02		10		361	
64.2		20	-	17	-				481	
65.2	8	10	13	4.2	0.1		18	420	164	
66.2		15	3	9.6	0.02		13		247	
67.2		20	-	17	-				329	
Buffer=N_2										
C=3.4 nF										
16.2	3	20	27	2.8	0.21		30	405	694	
17.2		15	25	1.6	0.19	12%	46		521	

18.2		10	9	0.71	0.07		>60		347	
19.2	5	10	0	0.71	0		-		240	
20.2		10	0	0.71	0		-	406	240	
21.2		15	19	1.6	0.15		50		361	
22.2		20	29	2.8	0.22		36		481	
23.2	8	10	0	0.71	0		-	407	164	
24.2		15	5	1.6	0.04		-		247	
25.2		20	21	2.8	0.16		38		329	
C=10.2 nF										
41.2	3	10	22	2.1	0.17		34	412	347	
42.2		15	19	4.8	0.15		19		521	
43.2		20	16	8.5	0.12		14		694	
44.2	5	10	6	2.1	0.05		34	413	240	
45.2		15	20	4.8	0.15		23		361	
46.2		20	19	8.5	0.15		15		481	
47.2	8	10		2.1					164	No disch
48.2		15	8	4.8	0.06		19	414	247	
49.2		20	5	8.5	0.04		14		329	
C=20.4 nF										
71.2		10	2	4.2	0.02		13	421	164	
72.2		15	0	9.6	0		-		247	
73.2		20	-	17	-				329	
74.2	5	15	0	9.6	0				361	
Buffer=SF_6										
C=3.4 nF										
26.2	3	10		0.71					347	No disch
27.2		15	10	1.6	0.08		41	408	521	
28.2		20	21	2.8	0.16		26		694	
29.2	5	10	-	0.71	-		-		240	No disch
30.2		15	-	1.6	-		-		361	No disch
31.2		20	0	2.8	0				481	
32.2	2	10		0.71					446	No disch
33.2		15	20	1.6	0.15	9%	49	409	669	
34.2		20	24	2.8	0.18		30		893	
C=10.2 nF										
35.2	2	10	16	2.1	0.12		25	410	446	
36.2		15	12	4.8	0.09		12		669	
37.2		20	3	8.5	0.02		7		893	
38.2	3	10		2.1					347	No disch
39.2		15	10	4.8	0.08		13	411	521	
40.2		20	3	8.5	0.02		6		694	
C=20.4 nF										
68.2	2	10	0	4.2	0		-		446	
69.2		15	0	9.6	0		-		669	
70.2		20	0	17	0		-		893	

Table 5. Discharge length is 30 cm, discharge volume is 360 cm^3, laser emitting volume is 216 cm^3.

Run ?	P_{buffer} Torr	U_{disch} V	E_{reg} mJ	E_{bank} specif J / l	E_{out} specif J / l	η_{chem} %	$T_{1/2}$ µs	? pic	E / N Td	Remarks
Buffer=He										
C=3.4 nF										
50.3	3	15	44	1.1	0.22	20%	66	306	347	
51.3		20	50	1.9	0.25		45		463	
52.3		10	10	0.47	0.05		-		231	
53.3	5	15	44	1.1	0.22	20%	60	307	240	
54.3		20	51	1.9	0.26		40		320	

55.3		10	10	0.47	0.05		-		161	
56.3	8	10	2	0.47	0.01		-	308	110	
57.3		15	38	1.1	0.19		56		164	
58.3		20	46	1.9	0.23		38		219	
C=10.2 nF										
23.3	3	15	47	3.2	0.24		24	297	347	
24.3		20	39	5.7	0.2		15		463	
25.3		10	45	3.2	0.17		37		231	
26.3	5	15	48	3.2	0.24		24	298	240	
27.3		20	46	5.7	0.23		19		320	
28.3		10	38	1.4	0.19		38		161	
29.3	8	15	48	3.2	0.24		26	299	164	
30.3		20	45	5.7	0.23		-		219	
31.3		20	47	5.7	0.24		22		219	
32.3		10	29	1.4	0.15		28		110	
C=20.4 nF										
1.3	3	15	>30	6.3	>0.15		-		347	
2.3		15	34.	6.3	0.17		14	290	347	
3.3		20	23	11.3	0.12		10		463	
4.3		10	>30	2.8	>0.15		26		231	
5.3		10	38	2.8	0.19		20	291	231	
6.3		15	33	6.3	0.17		-		347	
14.3	5	10	43	2.8	0.22		30	295	161	
15.3		15	49	6.3	0.25		20		240	
16.3		20	40	11.3	0.2		13		320	
17.3		15	44	6.3	0.22		-		240	
18.3	8	15	48	6.3	0.24		18	296	164	
19.3		20	46	11.3	0.23		14		219	
20.3		10	40	2.8	0.2		29		110	
Buffer=N_2										
C=3.4 nF										
59.3	3	20	43	1.9	0.22		-		463	
603		20	38	1.9	0.19		48	309	463	
61.3		15	29	1.1	0.15	14%	72		347	
62.3		10	-	0.47	-		-		231	No disch
63.3	5	10	0	0.47	0				161	
64.3		15	0	1.1	0				240	
65.3		20	36	1.9	0.18		56	310	320	
66.3	8	20	12	1.9	0.06				219	
C=10.2 nF										
33.3	3	15	38	3.2	0.19		19	300	347	
34.3		20	33	5.7	0.17		16		463	
35.3		10	0	1.4	0		-		231	
36.3	5	15	28	3.2	0.14		23	301-302	240	
37.3		20	33	5.7	0.17		21		320	
38.3		10	10	1.4	0.05		16		161	
39.3	8	-	-		-		-			No disch
40.3		20	14	5.7	0.07		8	303	219	
41.3		15	-	3.2	-		-		164	No disch
42.3		16	-	3.6	-		-	-	175	
C=20.4 nF										
7.3	3	15	27	6.3	0.14		17	292	347	
8.3		20	20	11.3	0.1		10		463	
9.3		10	0	2.8	0		-		231	
10.3	5	20	21	11.3	0.11		20	293	320	
11.3		15	2	6.3	0.01		7		240	
12.3	8	20	4	11.3	0.02		15	294	219	

13.3		15	0	6.3	0		-		164	
Buffer=SF_6										
C=10.2 nF										
43.3	2	20	26	5.7	0.13		6	304	595	
44.3		15	38	3.2	0.19	6%	12		446	
45.3		10	0	1.4	0		-		297	
46.3	3	20	21	5.7	0.11		-		463	
47.3		15	0	3.2	0		-		347	
48.3		20	23	5.7	0.12		-		463	
49.3		20	22	5.7	0.11		6	305	463	
C=20.4 nF										
21.3	3	20	0	11.3	0		-		463	Ark?
22.3	2	20	0	11.3	0		-		463	

Table 6. Discharge length is 40 cm, discharge volume is 480 cm^3, laser emitting volume is 288 cm^3.

Run ?	$P_{buffer,}$ Torr	$U_{disch,}$ V	$E_{reg,}$ mJ	E_{bank} spec J / l	E_{out} spec J / l	η_{electr} %	$T_{1/2}$ µs	? $_{pic}$	E / N Td	Remark
Buffer=He										
C=3.4 nF										
1.4	3	10	36	0.35	0.14	40%	>80	367	174	
2.4		15	78	0.79	0.3	38%	66		260	
3.4		20	83	1.4	0.32		46		347	
4.4		10	20	0.35	0.08		-		174	
5.4	5	10	-	0.35	-		-		120	No disch
6.4		15	73	0.79	0.28		63	368	180	
7.4		20	84	1.4	0.32		58		240	
8.4	8	10	-	0.35	-		-		82	No disch
9.4		15	70	0.79	0.27		76	369	123	
10.4		20	84	1.4	0.32		43		164	
C=10.2 nF										
22.4	3	10	61	1.1	0.23		54	372	174	
23.4		15	73	2.4	0.28		26		260	
24.4		20	63	4.3	0.24		18		347	
25.4		20	66	4.3	0.25		-		347	
26.4	5	10	-	1.1	-		-		120	
27.4		15	76	2.4	0.29		30	373	180	
28.4		20	68	4.3	0.26		22		240	
29.4	8	15	77	2.4	0.29		26	374	123	
30.4		20	78	4.3	0.3		23		164	
C=20.4 nF										
46.4	3	10	-	2.2	-		-		174	No disch
47.4		15	52	4.8	0.2		18	381	260	
48.4		20	31	8.6	0.12		10		347	
49.4		20	32	8.6	0.12		-		347	
50.4	5	15	58	4.8	0.22		20	382	120	
51.4		20	44	8.6	0.17		12		240	
52.4	8	15	68	4.8	0.26		22	383	123	
53.4		20	56	8.6	0.21		15		164	
Buffer=N_2										
C=3.4 nF										
11.4	3	10	-	0.35	-		-		174	No disch
12.4		15	52	0.79	0.2	25%	>80	370	260	
13.4		20	74	1.4	0.28		56		347	
14.4		20	52	1.4	0.2		-		347	
15.4		20	77	1.4	0.29		-		347	

16.4		20	72	1.4	0.28		-		347	
17.4	5	10	-	0.35	-		-		120	No disch
18.4		15	-	0.79	-		-		180	No disch
19.4		20	50	1.4	0.19		>80	371	240	
20.4	8	20	-	1.4	-		-		240	No disch
C=10.2 nF										
31.4	3	10	-	1.1	-				174	No disch
32.4		15	70	2.4	0.27		22	375	260	
33.4		20	64	4.3	0.24		17		347	
34.4		20	64	4.3	0.24		-		347	
35.4	5	15	0	2.4	0		-		180	
36.4		20	55	4.3	0.21		25	376	240	
37.4	8	20	-	4.3	-				164	No disch
38.4	3	20	64	4.3	0.24		20	377	347	
39.4		20	65	4.3	0.25		-		347	
C=20.4 nF										
54.4	3	10	0	2.2	0		-		174	
55.4		15	32	4.8	0.12		16	384	260	
56.4		20	32	8.6	0.12		10		347	
57.4	5	15	0	4.8	0		-		180	
58.4		20	31	8.6	0.12		22	385	240	
59.4	8	20	0	8.6	0		-		164	
Buffer=SF_6										
C=3.4 nF										
21.4	3	20	0	1.4	0		-		347	
C=10.2 nF										
40.4	2	15	62	2.4	0.24	10%	33	378	335	
41.4		20	50	4.3	0.19		12		446	
42.4	3	15	-	2.4	-		-		260	
43.4		20	50	4.3	0.19		52	379,	347	
44.4		20	28	4.3	0.11		> 80	379,	347	
45.4		20	48	4.3	0.18		60	380	347	
C=20.4 nF										
60.4	2	15	32	4.8	0.12		13	386	335	
61.4		20	5	8.6	0.02		5		446	
62.4		20	4	8.6	0.02		-		446	
63.4		15	23	4.8	0.09		-		335	
64.4	3	20	0	8.6	0		-		347	
65.4		20	0	8.6	0		-		347	

Table 7. Discharge length is 58,5 cm, discharge volume is 702 cm^3, laser emitting volume is 421 cm^3.

Run ?	$P_{buffer,}$ Torr	$U_{disch,}$ V	$E_{reg,}$ mJ	E_{bank} spec J / l	E_{out} spec J / l	η_{electr} %	$T_{1/2}$ μs	? $_{pic}$	E / N Td	Remarks
Buffer=He										
C=3.4 nF										
24.6	3	10	0	0.24	0.0		-	281	119	
25.6		15	34	0.54	0.13		>60		178	
26.6		20	60	0.97	0.23	24%	>60		237	
27.6	5	10	-	0.24	-		-		82	
28.6		15	31	0.54	0.12		-		123	
29.6		15	27	0.54	0.1		>60	282	123	
30.6		20	56	0.97	0.21		>60		164	
31.6	8	10	-	0.24	-		-		56	No discharge
32.6		15	0	0.54	0.0		-		84	

33.6		20	38	0.97	0.15		-		112	
34.6		20	42	0.97	0.16		-		112	
35.6		20	41	0.97	0.16		-		112	
36.6		20	40	0.97	0.15		55	283	112	
C=10.2 nF										
12.6	3	10	0	0.73	0.0		-		119	
13.6		15	67	1.6	0.26		44	277	178	
14.6		20	67	2.9	0.26		34		237	
15.6	5	10	0	0.73	0.0		-	278	82	
16.6		15	64	1.6	0.24		48		123	
17.6		20	73	2.9	0.28	10%	34		164	
18.6	8	10	0	0.73	0.0		-	279	56	
19.6		15	46	1.6	0.18		>		84	
20.6		20	29	2.9	0.11		>		112	*
21.6	8	10	-	0.73	-		-	280	56	No discharge
22.6		15	47	1.6	0.18		42		123	
23.6		20	64	2.9	0.24		32		164	
C=20.4 nF										
1.6	3	10	7.2	1.5	0.03		-	273	119	
2.6		15	>50	3.2	>0.19		-		178	
3.6		15	60	3.2	0.23		27	274	178	
4.6		20	58	5.8	0.22		23		237	
5.6	5	10	0	1.5	0.0		-	275	82	
6.6		15	62	3.2	0.24	8%	29		123	
7.6		20	59	5.8	0.23		23		164	
8.6	8	10	0	1.5	0.0		> 60	276	56	
9.6		15	47	3.2	0.18		> 60		84	
10.6		20	65	5.8	0.25		> 60		112	*
11.6		20	-	5.8	-		> 60		112	*
Buffer=N_2										
C=3.4 nF										
37.6	3	10	-	0.24	-		-		119	
38.6		15	0	0.54	0.0		-		178	
39.6		20	9	0.97	0.03		> 60	284	237	
40.6		20	8	0.97	0.03		> 60	285	237	
41.6	5	20							237	*
C=10.2 nF										
42.6	5	15	0	1.6	-.-		-	-	123	
43.6		20	20	2.9	0.08	-	-	-	164	*

The symbol "*" denotes discharge happens between the last cathode and flange of the laser chamber.

Unlike photolysis, which is a very selective tool for iodide decomposition, the electric discharge interacts with all components of active medium. Forming electrons, ions and different molecular fragments, electric discharge modifies the active medium composition. In its turn, the initial composition of an active medium is a factor determining the discharge parameters: breakdown voltage, electron distribution by energy, discharge resistance, etc. Thus, the interpretation of the results obtained is a very difficult task. Nevertheless, we shall try to evaluate the general rules in the behavior of the pulsed COIL with longitudinal discharge initiation.

The distinction of longitudinal and transverse discharge has two aspects. The first one is a geometric factor. The alignment of discharge direction with that of optical axis or flow makes it possible to save a degree of freedom to mount the magnets for Q-modulation. The second one is an electric factor. The term "transverse" usually applies to the discharge geometry when discharge gap is appreciably less the cross-size. In this case the discharge resistance is low. When resistant loaded pins electrode is used for discharge stabilization the energy stored in capacitor bank is distributed between the plasma and load proportionally to their resistance. So, the variation of plasma resistance due to buffer gas, for example, results in change of energy deposition into active medium.

In the case of longitudinal geometry, when electrode separation is long enough, the capacitor energy is wholly deposited into active medium. So, the energy deposition is governed by capacitor only. It results in less influence of buffer gas pressure on laser output energy and pulse duration as compared with that for transverse excitation. This effect is most strongly marked for He as a buffer gas. As it follows from tables 3 – 7, such a behavior is observed for all investigated lengths of discharge gap.

Another situation takes place when nitrogen N_2 is used as a buffer gas. In this case the pattern of buffer gas influence depends on the length of the discharge gap. Considering only the situations when the laser operates highly over the threshold one can see that for short discharge length the increase of nitrogen partial pressure results in initially weak and then sharp drop of output energy. At longer discharge length the sharp drop of output energy arrives at less nitrogen pressure. It means the buffer gas not only increases the heat capacity of active medium but significantly change the plasma parameters and, may be, the discharge uniformity.

This effect is more demonstrated for sulfur hexafluoride. Being very electronegative, SF_6 affects very strongly even at low concentration. Nevertheless, at short discharge length longitudinally excited COIL may operate with SF_6 as a buffer gas and, hence, chemical generation of iodine atoms due to reaction of fluorine atoms produced in a discharge with hydrogen iodide as an iodine donor is possible.

It was observed in the first experiments with electric discharge initiated pulsed COIL the output specific energy of such a laser is at disadvantage in relation to photolytically initiated one. The different factors can be the reason of such a phenomena. They are decrease of the singlet oxygen yield, forming the effective quenchers of excited states, heating of active medium and, hence, decrease of extractable fraction of energy stored in singlet oxygen. As it was shown the latter reason is the most possible.

The typical value of energy required to break the bond C-I in alkyliodides or perfluoro-alkyliodies is about 210 kJ/mol (53 kkal/mol for CF_3I, 54 kkal/mol for CH_3I). When photolysis is used to produce iodine atoms from these species which have a maximum absorption at the wavelength of about 270 nm the energy absorbed to produce one iodine atom is $7{,}4\cdot10^{-19}$ J (446 kJ/mol). Thus, the photo dissociation process is 225 kJ/mol exothermic. In fact the reaction is somewhat less exothermic because the fraction of iodine atoms is produced in excited state I ($^2P_{1/2}$) (92 kkal/mol). The yield of excited state strongly depends on the sort of iodine donor and assumed to be zero in this consideration. If one produces the iodine concentration of $1\cdot10^{18}$ l^{-3} that corresponds to the COIL pulse duration of about 10 µs, the UV energy absorbed in the active medium is 0,74 J/l. But only half of this quantity of energy (0.37 J/l) is transferred to translation degrees of freedom i.e.to heat.

Another situation takes place when electric discharge is used instead of photolysis. In this case, as it follows from the experimental results (see tables 3 –7), the comparable pulse duration is obtained when specific energy stored in the capacitor bank exceeds 8 J/l. When longitudinal discharge without ballast resistor is used, all energy stored in the capacitor bank is deposited into active medium. Thus, subtracting the energy consumed for breaking the CF_3 – I bond, one can evaluate the value of energy to be transferred to heat (7.63 J/l) twenty times as much as that in photolysis.

As soon as the active medium is practically immovable during the short pulse its temperature is governed by heat capacity C_v. The values of C_v for different components of the mixture at partial pressure 1 Torr are:

CF_3 I	$3.3\cdot10^{-3}$ J /l K
O_2	1.12
Ar, He	0.67
N_2	1.11
SF_6	4.72

Thus, for the typical mixture composition $O_2 : CF_3I : He = 1 : 0.5 :3$ Torr (run 48.4) one has $C_v = 4.78\cdot10^{-3}$ J /l K. The energy that can be theoretically transferred to heat is 8,23 J/l. Being wholly

transferred to translation degrees of freedom this energy results in $\Delta T = 1722$ K of temperature growth. This value is an upper limit of temperature growth. In fact, the real value of temperature is somewhat less because of excitation of rotation and vibration degrees of freedom of mixture components and formation of ions and different fragments. Such a great growth of temperature results in growth of threshold yield of singlet oxygen and, thus, in significant decrease of extractable energy. Indeed, the value of threshold yield

$$Y_{th} = 1/\ 1.5\exp(401/T) + 1,$$

has a limit $Y_{th} = 0{,}4$ when temperature tends to infinity. Thus, at the temperature $T = 2022$ K ($T_0 + \Delta T$) the value of threshold yield is $Y_{th} = 0{,}35$ instead of $Y_{th} = 0{,}\ 15$ at room temperature. A previously made investigations of sparger SOG used in experiments shows the yield of singlet oxygen $Y = 0{,}5 \pm 0.05$. One can derive that the extractable energy $E_{extract}$ under discharge initiation is $E_{extrac} = (0.10 - 0.20)[O_2]h\nu_{laser}$ instead of $E_{extrac} = (0.3 - 0.4)[O_2]h\nu_{laser}$. Having in mind that the real temperature growth is not so high one can conclude this effect is a primary reason of output energy drop when discharge is used instead of photolysis to initiate.

The special experiments were performed to evaluate the threshold yield and, thus, the real temperature of active medium. Unexcited oxygen was admixed to the active medium up to the concentration resulting in quenching of lasing. It is easy to show

$$Y_{th} = Y_0/(1 + \Phi_{O2}/\Phi_{Cl2}),$$

where Y_0 is an initial singlet oxygen yield, Φ_{Cl2} is a chlorine flowrate, Φ_{O2} is an additional oxygen flowrate resulting in quenching of lasing. It is obvious, these experiments were carried out with totally reflecting mirrors of laser resonator. The mixture composition $O_2 : CF_3I : N_2 = 1 : 0.5 : 3$ Torr and discharge length of 40 cm were used. For the cases of 20.4 nF capacitor bank, 20 kV of operation voltage and $\Phi_{Cl2} = 83.2$ Torr l /s the value $\Phi_{O2} = 62$ Torr l /s was obtained. Thus, assuming $Y_0 = 0.45 - 0.55$ one can evaluate $Y_{th} = 0.26 - 0.31$. Such values of Y_{th} correspond to the growth of temperature due to initiation energy deposition within the range of 326K – 716K. The conditions of experiments correspond to that of run 56.4,where the specific energy deposition is as large as 8.6 J/l. At the heat capacity of active medium $C_v = 6.1\cdot10^{-3}$ J /l K this value of energy deposition corresponds to the temperature growth of $\Delta T = 1410$K. This value is twice as much as that obtained via threshold yield. It may signify that not all energy deposited into active medium is transferred to translation degrees of freedom. Note, that energy consumed to produce iodine atoms is too small to be account.

The similar experiment made for the energy stored in capacitor bank of 1.4J ($C = 3.4$ nF, $U = 20$ kV) gives the growth of temperature $\Delta T = 280$K. The same parameter evaluated from deposited energy and heat capacity is $\Delta T = 240$K. It is seen both values are in a good agreement. Note, that because of a weak dependence of threshold yield on temperature at high values of temperature the accuracy of temperature measurement via threshold yield drops with temperature increase.

As it follows from aforesaid at high energy deposition the chemical efficiency has a theoretical limit of about 20% ($Y_0 = 0.45 - 0.55$, $Y_{th} = 0.26 - 0.31$). But it was shown in experiments with transverse discharge the specific output energy of 0.5 J/l is obtainable at oxygen pressure 1 Torr. This value of specific energy corresponds to 10% of chemical efficiency. This fact demonstrates a very high efficiency of laser energy extraction from active medium.

Thus, the electric discharge initiation of pulsed COIL creates specific conditions of its operation. Unlike CW supersonic mode of COIL operation when the active medium temperature is low, the pulsed COIL with discharge initiation works under high temperature (close to 1000K) of active medium. This situation requires the new kinetic information on rate constants of processes which are critical for laser operation. The first of them is temperature dependence of energy exchange between singlet oxygen and iodine atom. In application to supersonic cw operation this process was under deep investigation for temperatures below room ones. As to temperature region above 300K, it is not investigated so deeply. The different temperature dependences are reported in literature, $K(T)=2.3\cdot10^{-8}/T$ [5], $K(T) = 5.12\cdot10^{-12}\cdot\sqrt{T}$ [6]. The correct temperature dependence of

rate constant is necessary for adequate modeling of laser operation. Our evaluations of iodine atom concentration from duration of a laser pulse were made using the room temperature value for energy transfer constant. One can see the real concentration can be several times higher.

The high temperature active medium being produced in the electric discharge initiated COIL is a model of active medium which, one can expect, can be produced in Electri COIL, i.e. oxygen-iodine laser with electrical SOG. Indeed, production of 40% yield of singlet oxygen in pure oxygen with concentration of 10^{21} cm^{-3} (corresponds to 30 Torr at room temperature) requires the energy deposition of 125 J/l. At the efficiency of the excitation process of 50% [7] the energy transferred to translation degrees of freedom is 62 J/l. The heat capacity of oxygen at pressure 30 Torr is about $34 \cdot 10^{-3}$ J /l K. Thus, the growth of active medium temperature can achieve $\Delta T = 1823$K. To drop this high temperature the adiabatic expansion in supersonic nozzle is used. But even Mach number M=3 makes it possible to drop temperature to only T=764K. Note, the density of oxygen at this Mach number drops to $8 \cdot 10^{16}$ cm^{-3}.

The output energy is one of the key parameters defining laser operation. Figures 3 – 11 demonstrate the influence of initiation length (discharge gap length) on the laser output energy for He as a buffer gas and for different initiation conditions (voltage, bank capacity). One can see the output energy grows proportionally with initiation length, at least for lengths over the threshold one. It means, as a first approximation, the output energy doesn't depend on initiation energy and reduced electric field strength. These parameters can be more essential for iodine atom generation. The influence of initiation energy on laser output brings mainly via heat effects i.e. grows of a threshold yield and gain drop. The fact the dependence falls off linear for initiation length of 600 mm can be explained as a mutual influence of singlet oxygen relaxation, low specific initiation and, may be, discharge nonuniformity.

The temporary laser pulse behavior is governed by mainly the specific energy deposited into active medium. The comparison of results obtained for discharge length 20 cm and 60cm shows the pulse durations of 38 µs (run 5.2) and 44 µs (run 13.6) are obtained for specific deposition energy of 8.6 J/l. Note, the values of reduced electric field strength differs about three times (521 Td and 178 Td, respectively).

Like that observed under initiation with transverse electric discharge, the pulse duration depends on deposition energy. At the case of investigated earlier transverse resisitively stabilized discharge the energy stored in capacitor bank shared between resistors and plasma. Having no information on volt-ampere characteristic of discharge, it is impossible to determine the value of energy deposited into active medium. In longitudinal discharge practically all energy is deposited into active medium. This fact makes it possible to evaluate the energy cost of iodine atom produced by discharge. Thus for the pulse duration of 10 µs (run 48.4,) energy deposition is 8.6 J/l = $53 \cdot 10^{18}$ eV/l and iodine atom concentration determined through pulse duration is $1.3 \cdot 10^{18}$ l^{-3}. So the energy cost of iodine atom in experiment is about 41 eV/atom. Note, this value is one-fifth as large as that reported for transverse discharge initiation at the same pulse duration.

The same energy deposition into active medium with SF_6 resulted in pulse duration as short as 5 µs (run 61.4). This fact shows the influence of plasma parameters on process of iodine atom formation.

4. Pulsed COIL based on the Jet SOG

The motivations for investigation of the pulsed chemical oxygen-iodine laser based on the jet singlet oxygen generator are the promising results obtained in investigation of the features of pulsed COIL initiation with transverse discharge [8], as well as results of numerical analysis and experimental study of COIL with generation of singlet oxygen via photolytic ozone decomposition [9]. It was shown in [9] that pulsed COIL output energy increased linearly with the growth of the oxygen pressure.

The value of specific energy, that is energy obtained from the unit of the volume of the active medium, is a crucial factor which governs the mass and dimension of laser. Thus the trend to increase the operation pressure is motivated. So far, all experiments with discharge initiation of

pulsed COIL were carried out using the sparger singlet oxygen generator. Unfortunately, due to strong dependence of singlet oxygen yield on operation pressure, such a SOG makes it possible to work at oxygen pressure not over 2-3 Torr.

Recently, Japanese scientists attempted to get COIL operation using the porous high pressure SOG and method of volume generation of atomic iodine from CH_3I [10]. The experiments made at the pressure over 30 Torr results in 2.8 J/l of specific output energy and 2 ms of pulse duration. The result obtained are far from that one could expect. By the way, the similar result was obtained earlier when molecular iodine was used as iodine donor. It means, the author failed to realize the method of volume iodine generation completely. The most possible reason why the low result was obtained, is a low efficiency of chlorine utilization and, hence, relatively high chlorine concentration. It was shown in works carried out earlier in LPI, the chlorine being mixed with singlet oxygen decompose molecules of alkyliodide and release the free iodine atoms thus forming the active medium one has when singlet oxygen is mixed with I_2.
Note, the long pulse duration is evidence of more of cw operation than pulsed one.

The jet SOG is a source of high-pressure singlet oxygen too. The experiments described above showed the operation conditions when chlorine utilization is rather high. So, one can expect the influence of release of free iodine atoms will be negligible.

4.1. Experimental

The layout of experimental set up is shown in Fig. 12
The jet SOG used is described above. The discharge chamber made of PMMA has a length 5 cm. The laser is initiated by a discharge occurring between the bulk anode and multi pin cathode. To stabilize the discharge each of pins is loaded with an active resistor R = 150 Ω. The full number of pins is 34. The electrodes are 2 cm spaced. So the active medium volume is 20 cm^3. The capacitor bank consist of ceramic C = 4.7 nF capacitors KVI. The necessary capacitance and operation voltage of the bank is obtained by connecting several units in parallel or in series. The investigated region of capacitance is from 2.3 to 7 nF. Operation voltage is 16 kV. The trigger generator provided the discharge repetition frequency of about 1 Hz.

The laser optical cavity is formed with spherical and plane mirrors spaced by 70 cm. The generation parameters are detected with calorimeter IMO-2N and Ge-photodetector.

Singlet oxygen produced in the jet SOG is fed to laser chamber through the transport section of 20x50 mm cross-section and 160 mm length. The pump rate in the SOG is controlled via injection of necessary flow of buffer gas N_2 through the tube injector o.d. 8mm placed near the inlet of transport section. Iodide is injected into $N_2 – O_2$ mixture 60 mm downstream of N_2 injector. The iodide mixing length is 105 mm.

The laser chamber used was previously designed to work in joint experiments with Samara branch of LPI and comparison of CW and pulsed modes of COIL operation. It governed the dimensions of laser chamber. But, as it follows from the analysis of the temperature working conditions of active medium in the case of discharge initiation, the chosen dimension of laser chamber is not enough to provide the laser operation over threshold. Indeed, the typical iodine atom concentration in supersonic cw COIL is about 10^{15} $?m^{-3}$. It follows from the experiments on the pulsed COIL initiated by the longitudinal electric discharge to create such a concentration needs to deposit into active medium energy of 10 J/l. The specific heat capacity of the mixture of oxygen and nitrogen under 15 Torr is $C_v = 16{,}8 \cdot 10^{-3}$ J/l? . Thus the temperature increase is $\Delta? = 600$? . It means the temperature of active medium can achieve the value of 900K. Under such a temperature the small signal gain is $G_0 = 7{,}8 \cdot 10^{-4}$ $?m^{-1}$ at singlet oxygen yield Y=50%. So the total gain at the double pass length L= 10 ?m is $G = 7{,}8 \cdot 10^{-3} = 0{,}78\%$.

The temperature of active medium in the case of supersonic cw COIL is but 150K. This value at the similar operation condition corresponds to the small signal gain of $G_0 = 5{,}4 \cdot 10^{-3}$ $?m^{-1}$ and total gain of G = 5,4%. Thus, pulsed laser with discharge initiation has a gain one order of magnitude less. So, the laser operation needs application of mirrors with high reflection. Such mirrors,as a rule, have relatively high level of losses.

4.2. Results and discussion.

In all previous experiments with pulsed COIL initiated by transverse electric discharge the sparger SOG was used. It is known the yield of singlet oxygen in SOG of this type drops with increase of operation pressure. It results in decrease of output laser energy at oxygen pressure over 3 Torr. The goal of current investigation is a stud of oxygen pressure influence on output energy for the pressures within 3 – 10 Torr.

When BHP jets are injected into low pressure medium of SOG the gas saturated liquid comes to the boil, thus producing the drops. The drops are carried out by gas flow from SOG to laser chamber thus resulting in experiment break-down. To avoid this effect the buffer gas is fed to the pressure of 10 Torr and then the chlorine flow is fed. The pressure in the SOG is a sum of that for Chlorine, nitrogen and iodide. At the same time, the oxygen partial pressure in the laser chamber is equal to total pressure divided by ratio of nitrogen flowrate to that of oxygen. As the flow velocity is subsonic the total pressure in the laser chamber is equal to that in the SOG.

Because of large idle volume of experimental set-up and low chlorine flowrate the transient period for gas flow is too long. One can assume this effect is responsible for degradation of laser pulse parameters during the run (Fig.13). The pulse amplitude decreases with time and, hence, increase of oxygen pressure. The pulse shown in the picture was obtained at the oxygen pressure of 4.7 Torr and iodide pressure of 1.2 Torr. Iodide methyl CH_3I was used as an iodine atom donor. As it was shown [11], this iodide provides the better energy parameters of laser. But its merit takes place when active medium is free of chlorine. The experiments show that in spite the SOG operates under conditions when the chlorine utilization is maximal, the concentration of residual chlorine is enough to cause the active medium to be unstable. It is a reason why we could not increase the CH_3I pressure and make a laser to work over the threshold.

One could expect the substitution of CH_3I for CF_3I results in a significant improvement of laser performance. In fact, it is a problem to say about any energy parameter when the laser operates with a totally reflecting mirrors.Nevertheless, we succeeded to get the laser operation under oxygen pressure in laser cavity of 7 Torr, iodide pressure of 1.8 Torr and total pressure of 17 Torr. Note the pulse duration obtained was as short as 5 µs.

5. Conclusion

1. The experiments with pulsed COIL initiated with a longitudinal electric discharge showed the initiation length up to 60 cm is available in the active medium conditions close to that of cw laser. It is shown the active medium temperature growth after discharge can be responsible for the specific output energy drop as compared to photolytic initiation.

2. The laser effect is obtained with the pulsed COIL based on the jet singlet oxygen generator. The operation pressure is obtained under the total pressure of 17 Torr and oxygen partial pressure of 7 Torr. The laser operation under the high pressure makes it possible to reduce the pump rate and, thus, to minimize the weight and size of the laser.

6. References

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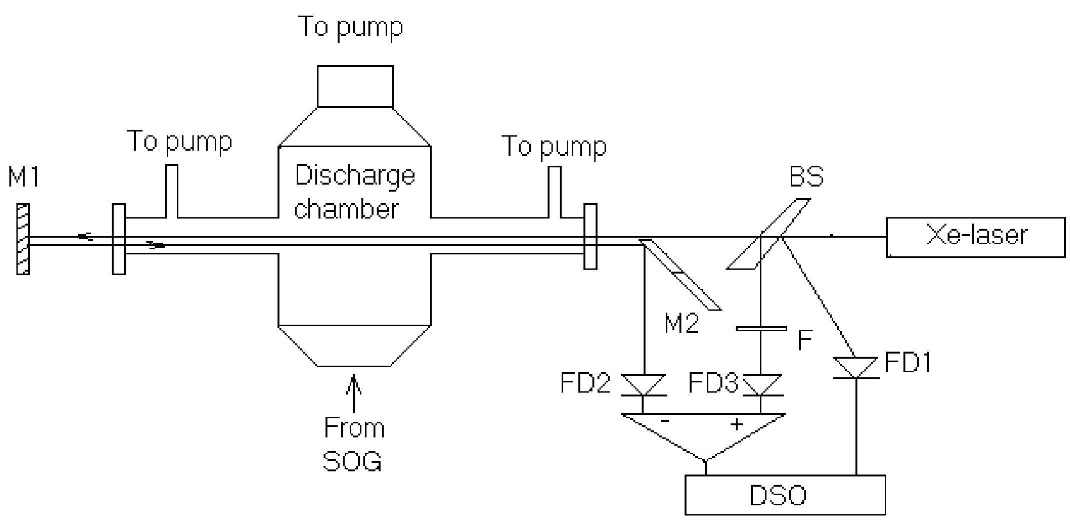


Fig.1. Schematic diagram of measuring the residual chlorine concentration.

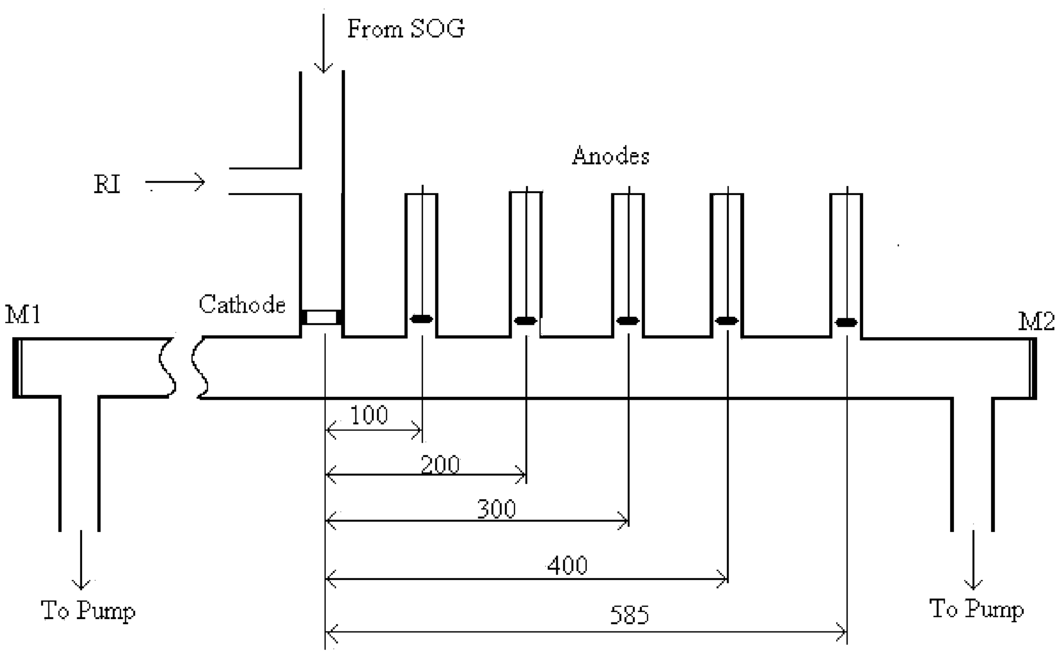
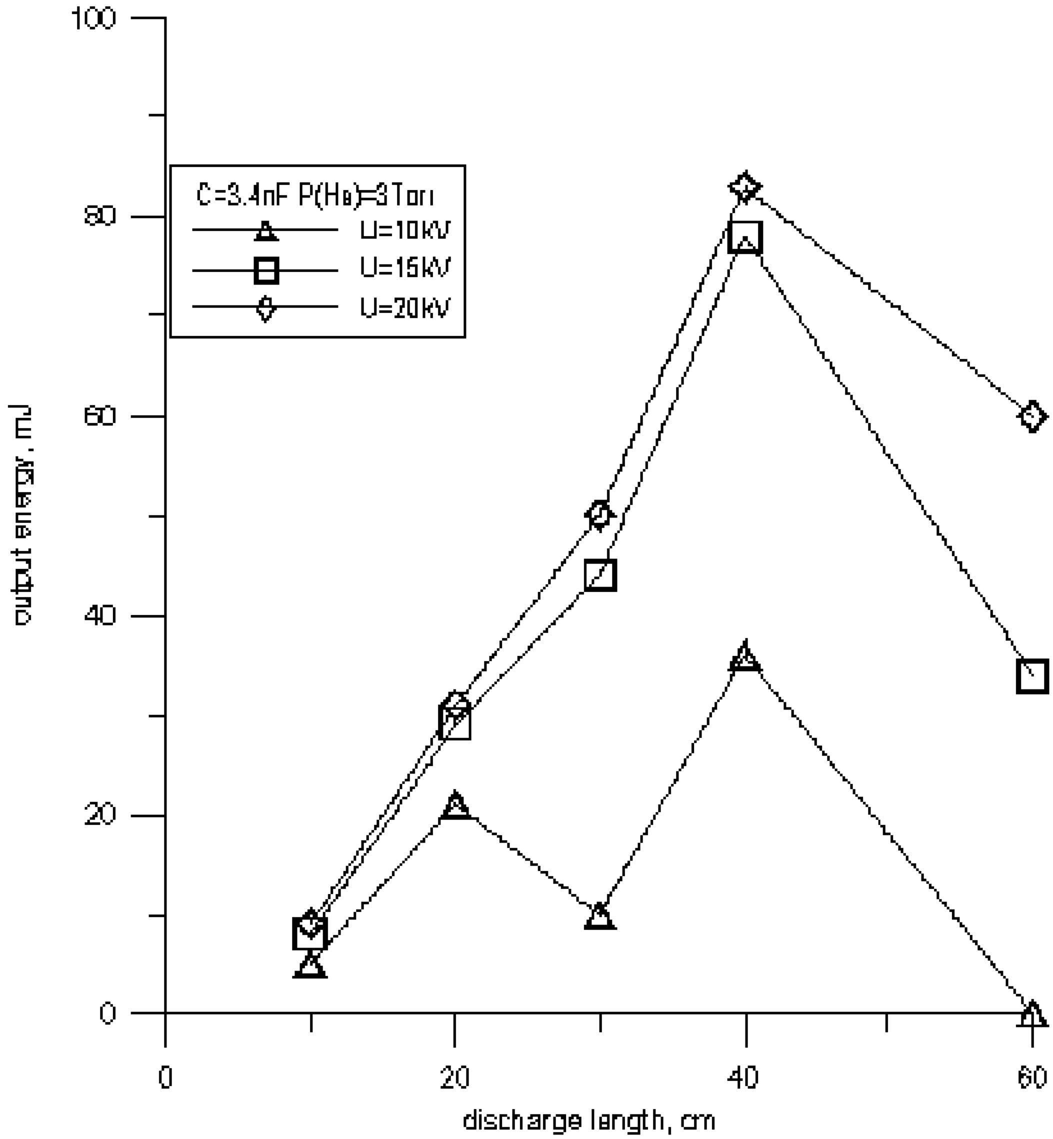


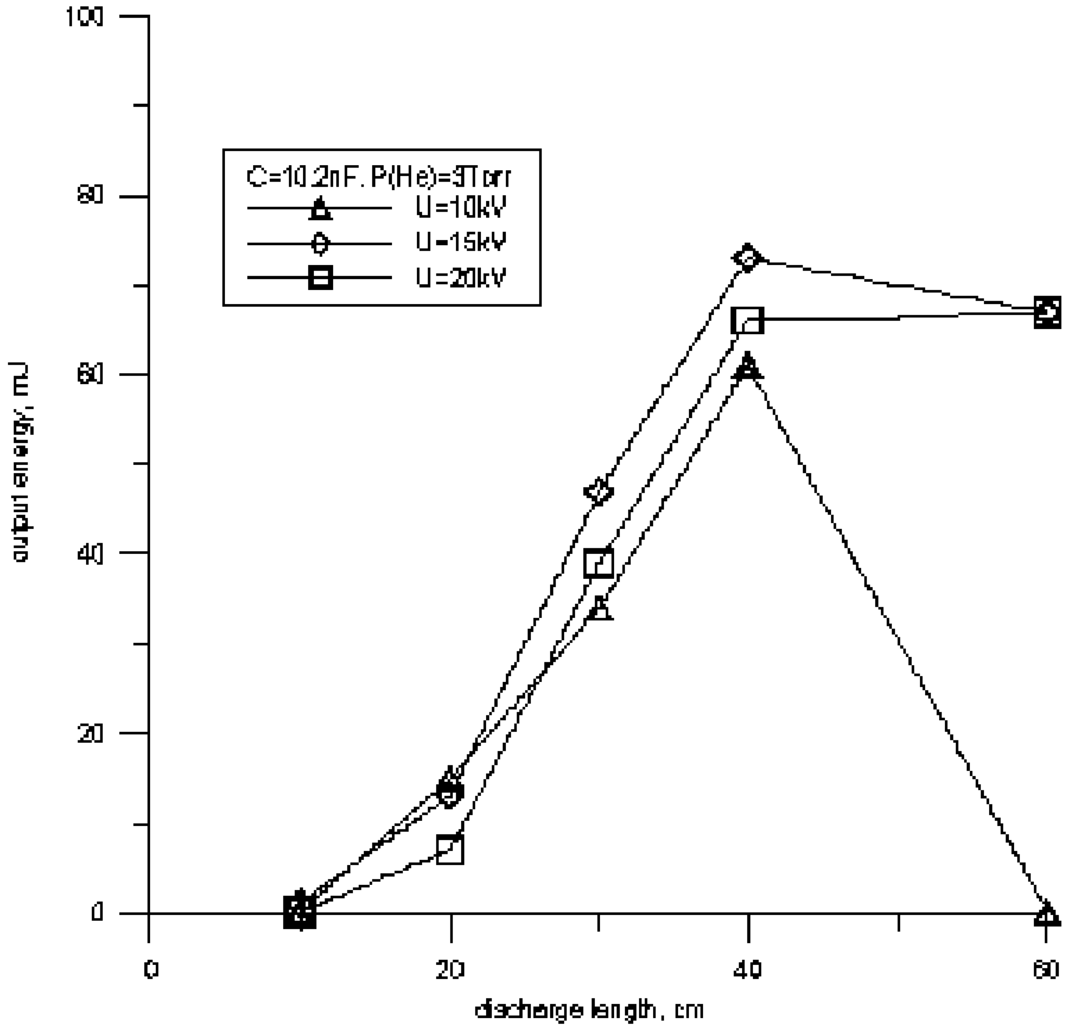
Fig.2. Schematic diagram of the discharge chamber used in investigation of a pulsed COIL initiated with a longitudinal glow discharge.

Fig. 3



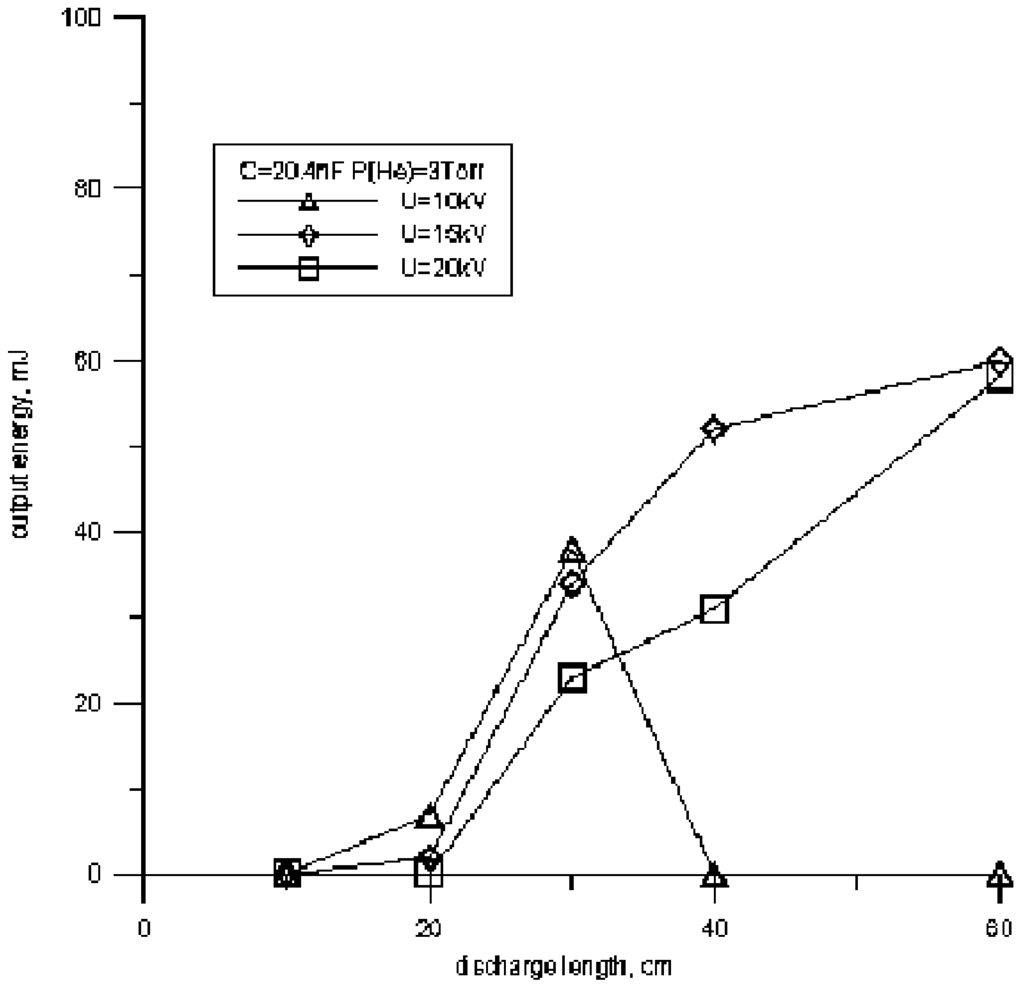
C=3.4nF P(He)=3Torr
U=10kV
U=15kV
U=20kV
output energy, mJ
discharge length, cm
0
20
40
60
80
100

Fig. 4



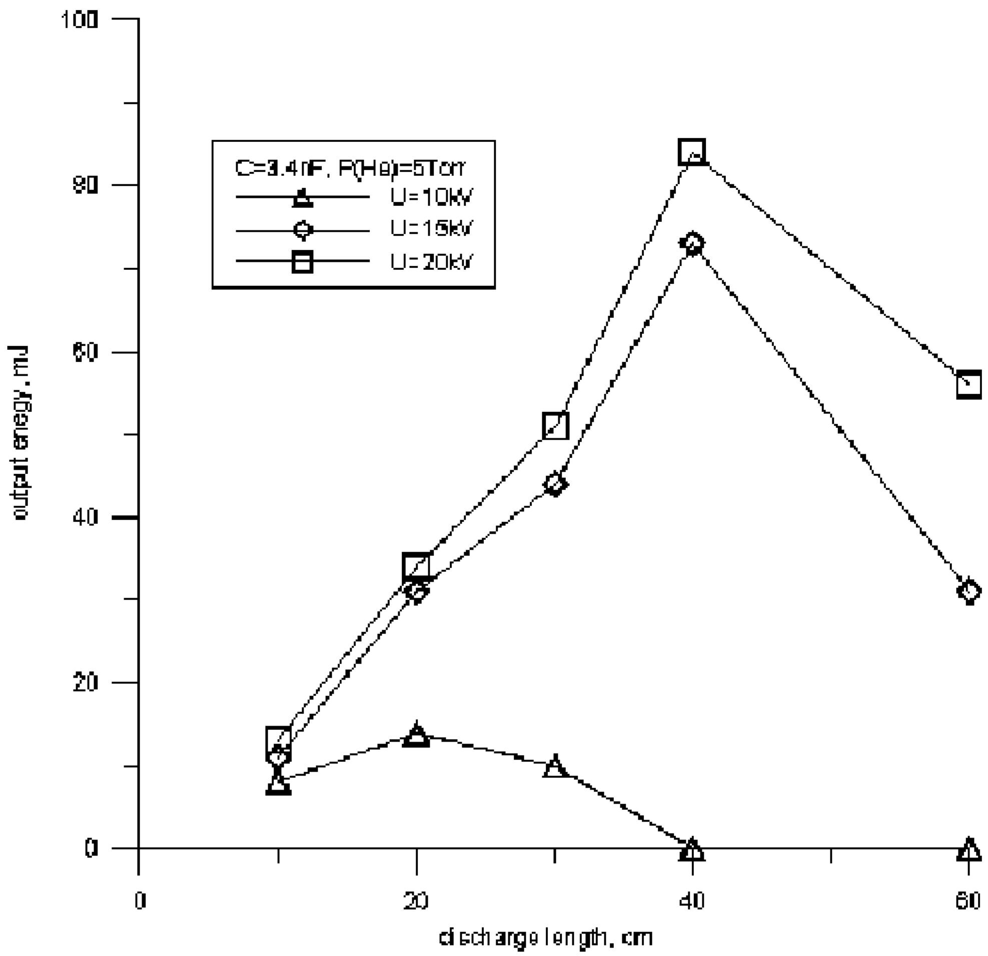
C=10.2nF, P(He)=5Torr
U=10kV
U=15kV
U=20kV
output energy, mJ
discharge length, cm
0
20
40
60
80
100

Fig. 5



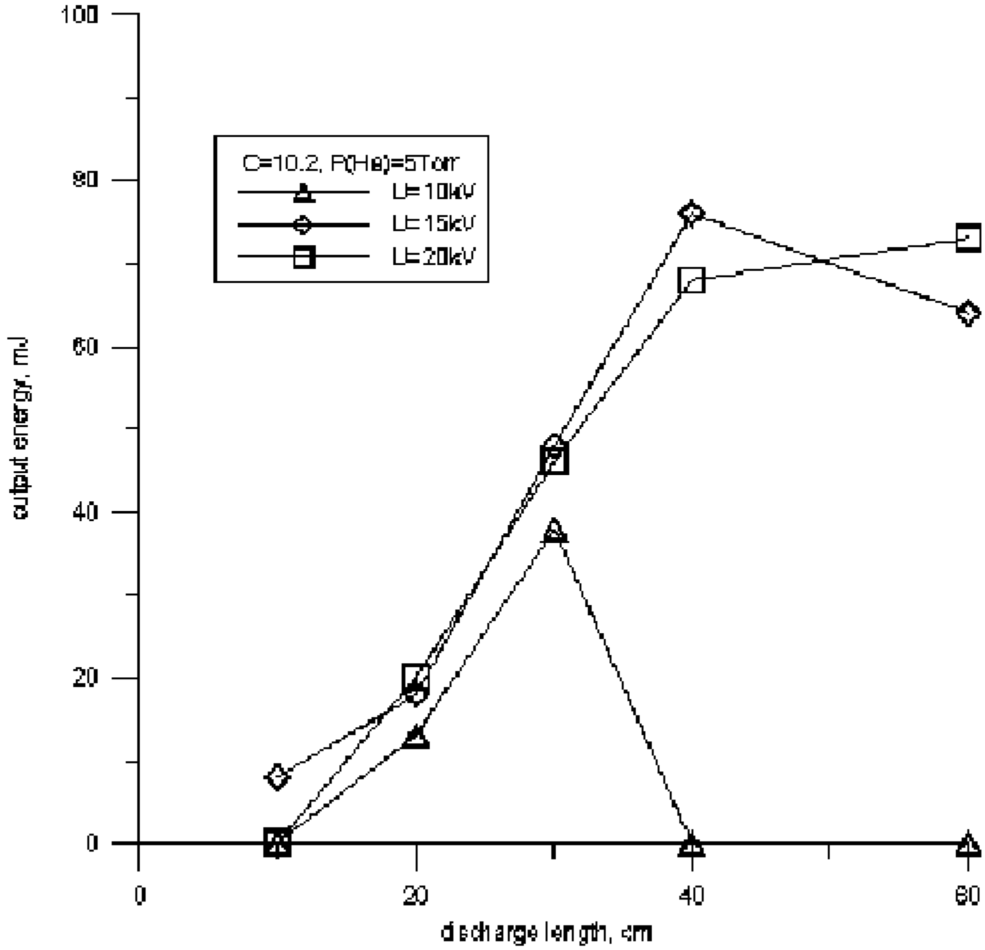
C=20.4nF P(He)=3Torr
U=10kV
U=15kV
U=20kV
output energy, mJ
discharge length, cm
100
80
60
40
20
0
0
20
40
60

Fig. 6



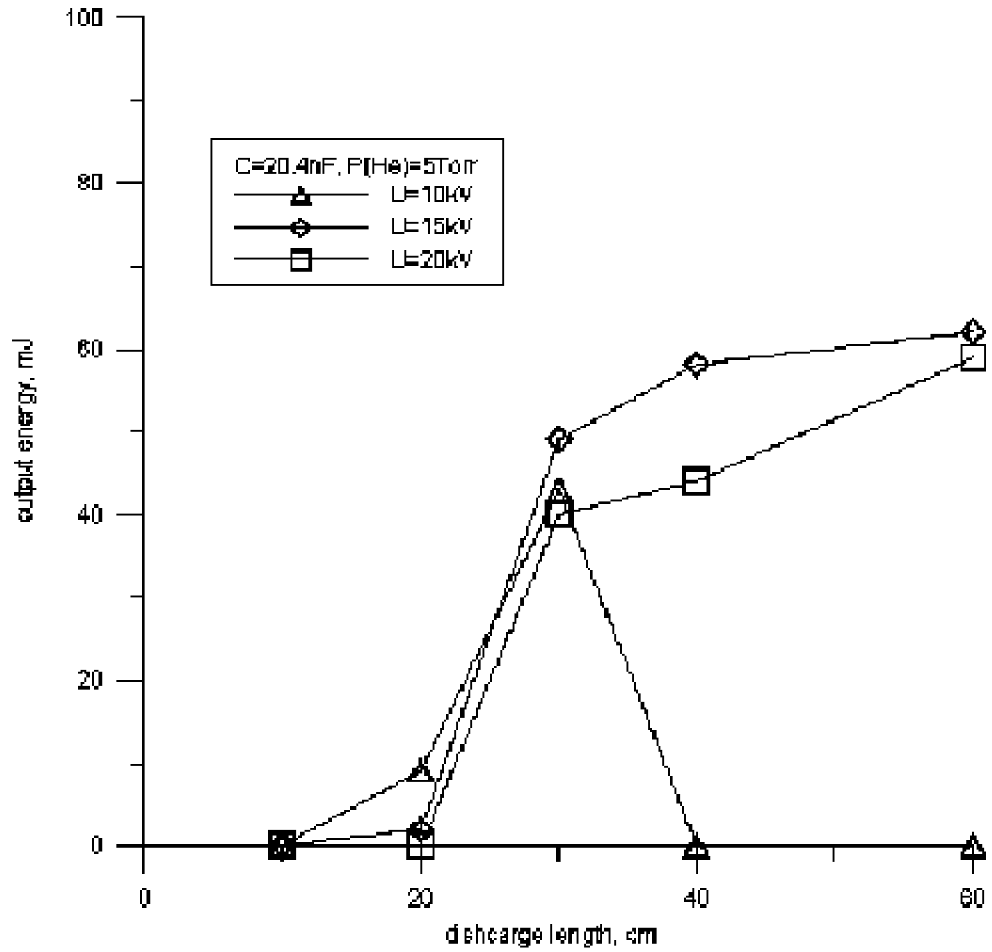
C=3.4nF, P(He)=5Torr
U=10kV
U=15kV
U=20kV
output enegy, mJ
discharge length, cm
0
20
40
60
80
100
0
20
40
60

Fig. 7



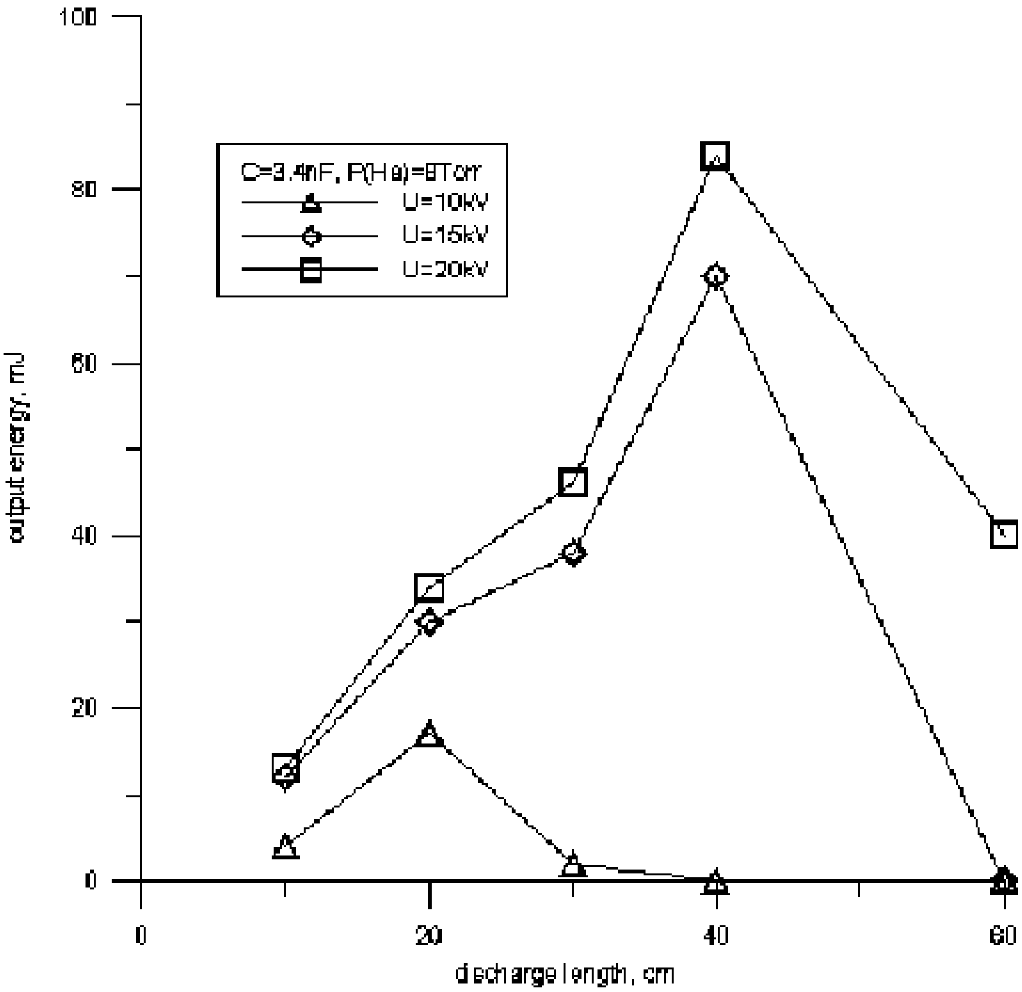
C=10.2, P(He)=5Torr
U=10kV
U=15kV
U=20kV
output energy, mJ
discharge length, cm
0
20
40
60
80
100

Fig. 8



C=20.4nF, P(He)=5Torr
U=10kV
U=15kV
U=20kV
output energy, mJ
discharge length, cm
0
20
40
60
80
100

Fig. 9



C=3.4nF, P(He)=8Torr
U=10kV
U=15kV
U=20kV
output energy, mJ
discharge length, cm
0
20
40
60
80
100

Fig. 10

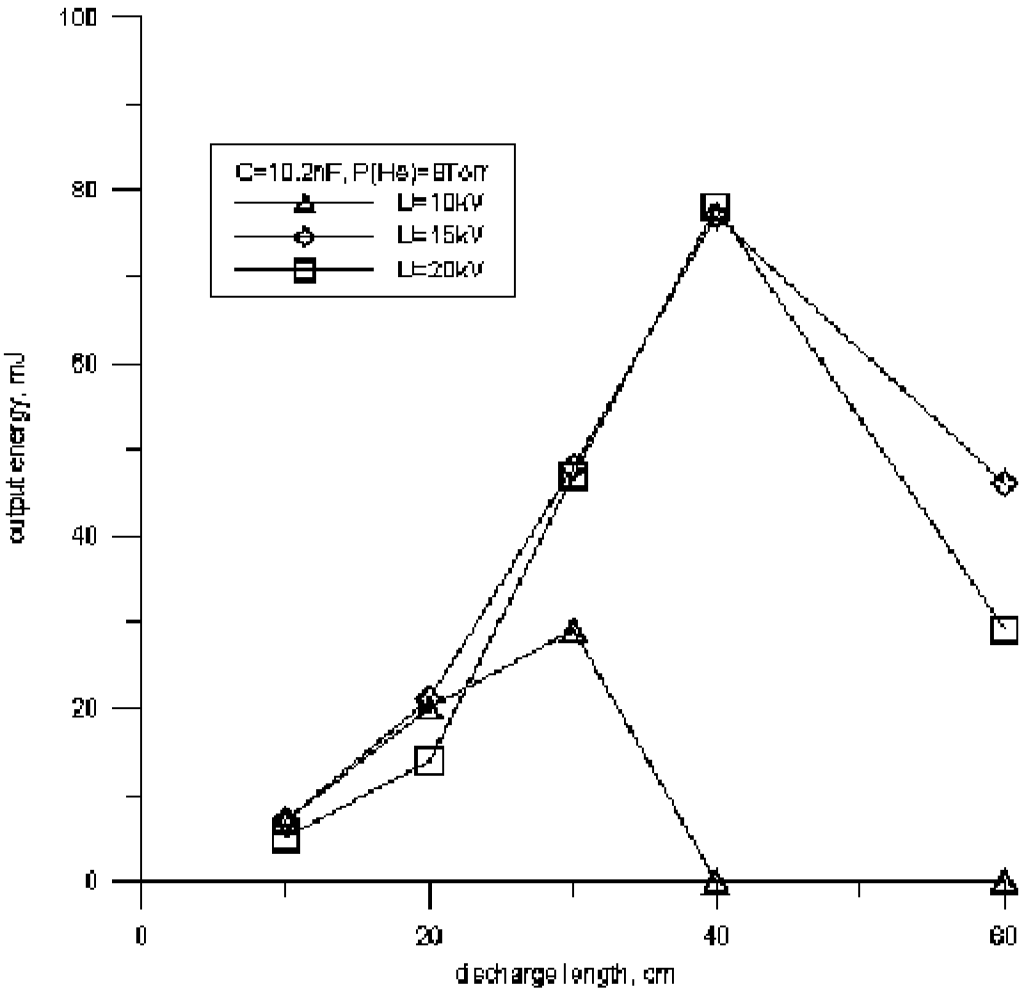
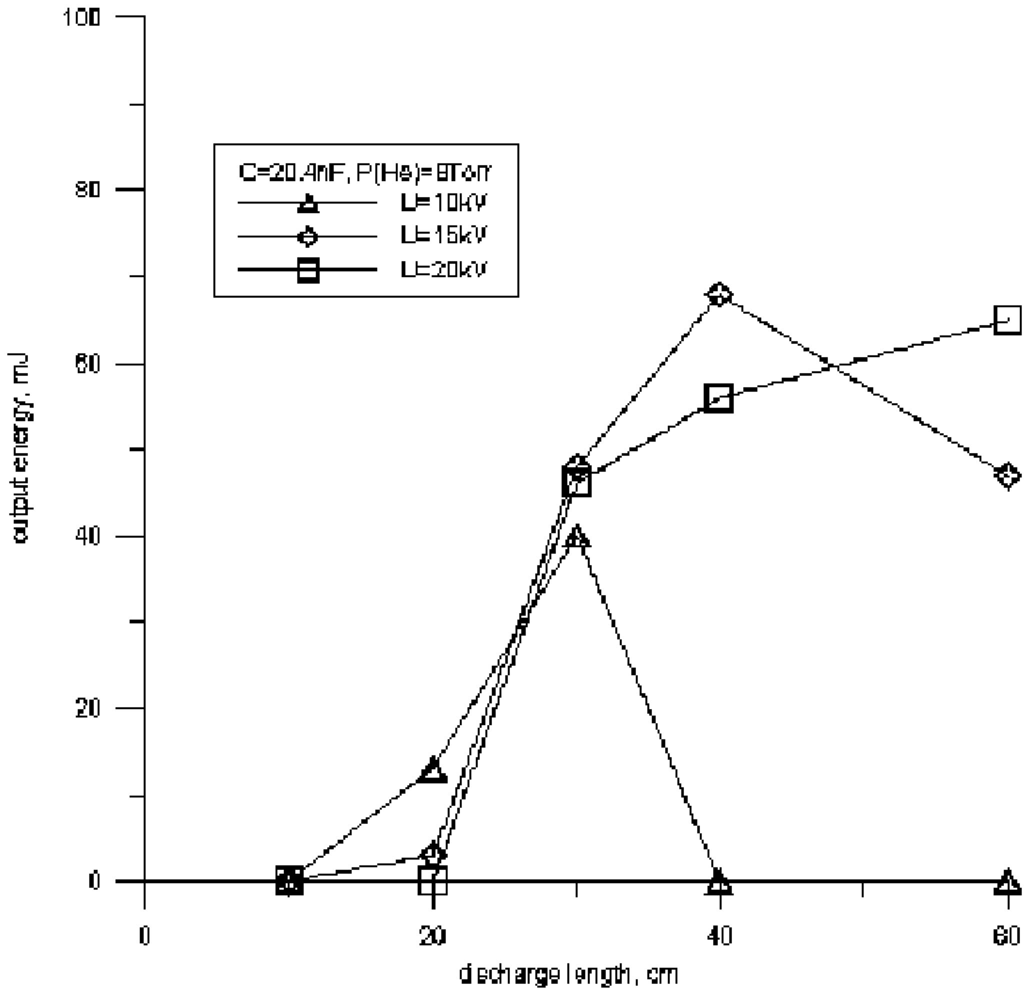

C=10.2nF, P(He)=8Torr
U=10kV
U=15kV
U=20kV
output energy, mJ
discharge length, cm
0
20
40
60
80
100

Fig. 11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U=10kV
U=15kV
U=20kV
output energy, mJ
discharge length, cm
0
20
40
60
80
100
0
20
40
60

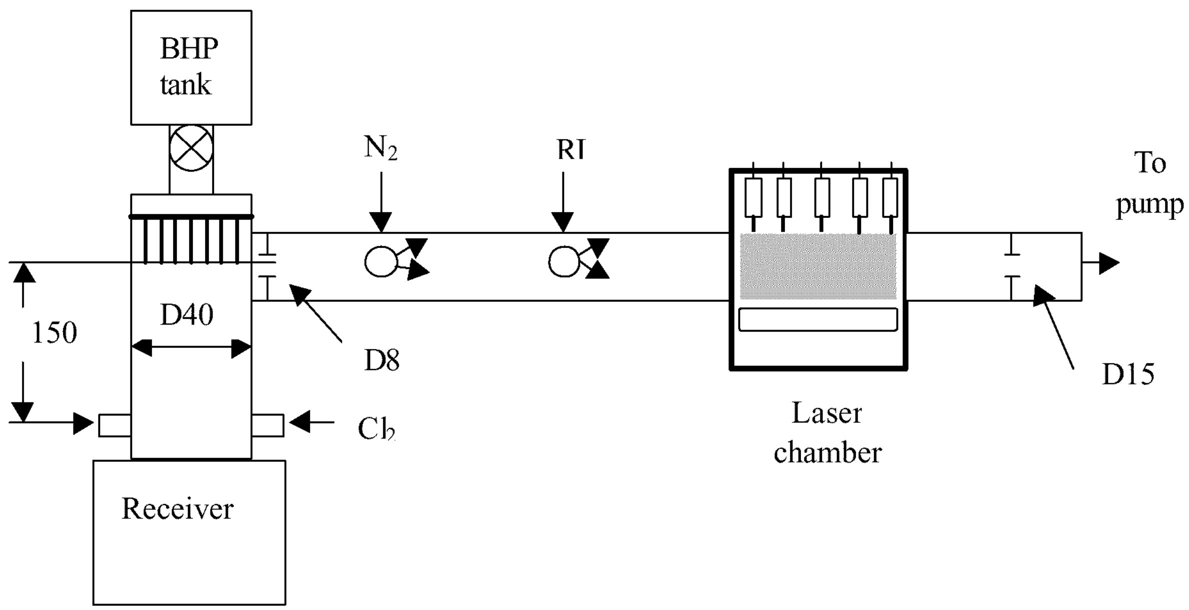

Fig.12. Schematic diagram of experiment with pulsed COIL based on a jet SOG.

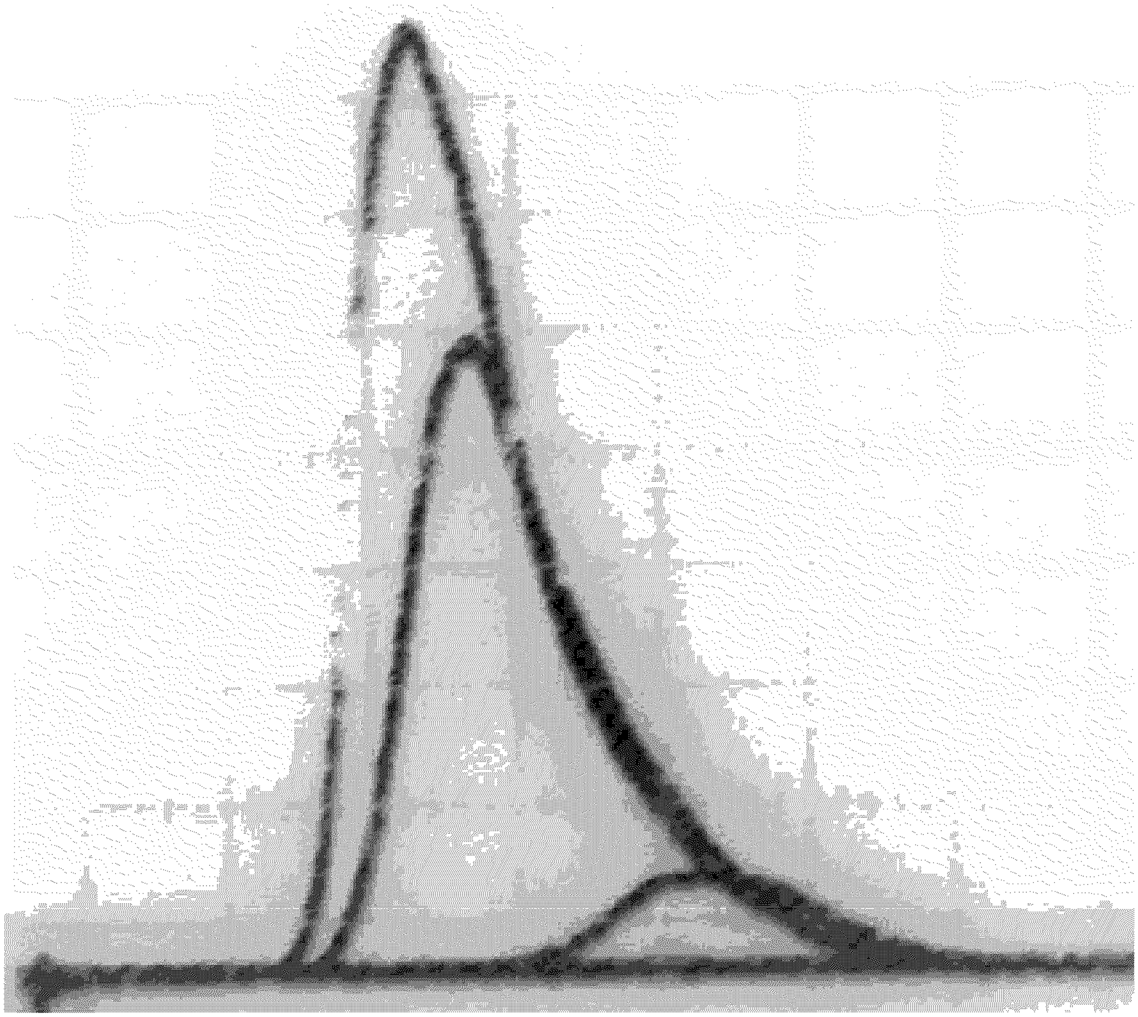

Fig.13. The train of laser pulses from pulsed COIL based on the jet SOG